Astrophysics/Cosmology Working Group
Barwick and Beacom, co-leaders

APS Neutrino Study

John Beacom

Fermilab ---> Ohio State University

Key Recommendations

1. We strongly recommend the development of new experimental techniques for the detection of astrophysical neutrinos in the energy range above 1 PeV (10^15 eV).

2. We strongly recommend new experiments for precision measurements of neutrino-nucleus cross sections in the energy range of a few tens of MeV.

So what would it cost?

Enthusiastic Support

1. We recommend continued investment in a vigorous and multi-pronged effort to precisely measure the cosmological neutrino background (indirectly).

2. We recommend that additional support be directed at theoretical efforts integrating the latest results in astronomy, astrophysics, cosmology, particle physics, and nuclear physics, and how they constrain the properties of neutrinos and their role in the universe.

3. We endorse and confirm the current program in neutrino astrophysics experiments, including IceCube, ANITA, AUGER, etc.

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4. It is extremely important that solar, reactor, proton decay, and long baseline experiments have the maximum sensitivity to supernova neutrinos, and also the maximum possible exposure duration. Also the diffuse supernova neutrino background from all supernovae in the universe.

5. Though solar neutrinos were not in our purview, we endorse the conclusion of the Solar/Atmospheric Working Group that it is important to precisely measure solar neutrinos, particularly in detectors which could also be used for direct dark matter detection, a topic of absolutely fundamental interest for particle physics, astrophysics, and cosmology.

Participants, Page 1

Working Group Leaders

Steve Barwick (UC Irvine)

John Beacom (Fermilab)

Participants at Argonne meeting:

Baha Balantekin	Ernie Henley	Doug McKay
Nicole Bell	Albrecht Karle	Paul Nienaber
Dick Boyd	Teppei Katori	Keith Olive
Mu-Chun Chen	Boris Kayser	Tatsu Takeuchi
Vince Cianciolo	Paul Langacker	Jon Thaler
Mike Dragowsky	John LoSecco	Neil Weiner

Participants, Page 2

New participants since Argonne meeting:

Gianfranco Bertone	Cecilia Lunardini	Sylvia Pascoli
Lali Chatterjee	Misha Medvedev	Rob Plunkett
Scott Dodelson	Peter Meszaros	Georg Raffelt
Jonathan Feng	Tony Mezzacappa	Todor Stanev
George Fuller	Irina Mocioiu	Mark Vagins
Manoj Kaplinghat	Hitoshi Murayama	Terry Walker
John Learned	Sergio Palomares	Bing-Lin Young

Working Group Assignments

Our goal is to produce a 30-40 page document that makes a clear and compelling case for the importance of new experiments and observations that (a) provide unique tests of the properties of neutrinos, and/or (b) use neutrinos as a new probe of the universe and its evolving contents. We also want to build on the recent successes in this field, and to highlight the inescapable connections between progress in astrophysics/cosmology and particle/nuclear physics.

Our WG identified 12 key opportunities and found 12 volunteers to write about 3 pages each, to be due by 1 May 2004. We will merge and refine them, and title the final product

Steal This Proposal

The 12 Topics

Neutrino Astronomy

1. Origin and nature of the cosmic rays
Todor Stanev @ Bartol

2. GZK neutrino detection and new physics above a TeV
Doug McKay @ Kansas

3. Neutrino probes of high energy astrophysical sources
Peter Meszaros @ Penn State

4. Dark matter searches using neutrinos
Jonathan Feng @ Irvine

The 12 Topics

Supernova Neutrinos

5. Neutrinos as a probe of supernovae
Tony Mezzacappa @ Oak Ridge

6. Supernova neutrinos as tests of particle physics
George Fuller @ San Diego

7. Diffuse supernova neutrino background
Terry Walker @ Ohio State

8. Measurements of neutrino-nucleus cross sections
Vince Cianciolo @ Oak Ridge

The 12 Topics

Neutrino Cosmology

9. Leptogenesis and the origin of the baryon asymmetry
Hitoshi Murayama @ Berkeley

10. Precision big bang nucleosynthesis tests
Keith Olive @ Minnesota

11. Precision cosmic microwave background tests
Manoj Kaplinghat @ Davis

12. Neutrino mass and large scale structure
Scott Dodelson @ Fermilab

Key Observational Results

Cosmological

- Big-bang nucleosynthesis consistency
- Neutrino hot dark matter models ruled out

Astrophysical

- Neutrinos from SN 1987A observed
- The solution of the solar neutrino problem

Fundamental

- Neutrinos have mass and mixing
- Non-discovery of all manner of exotica

The Future

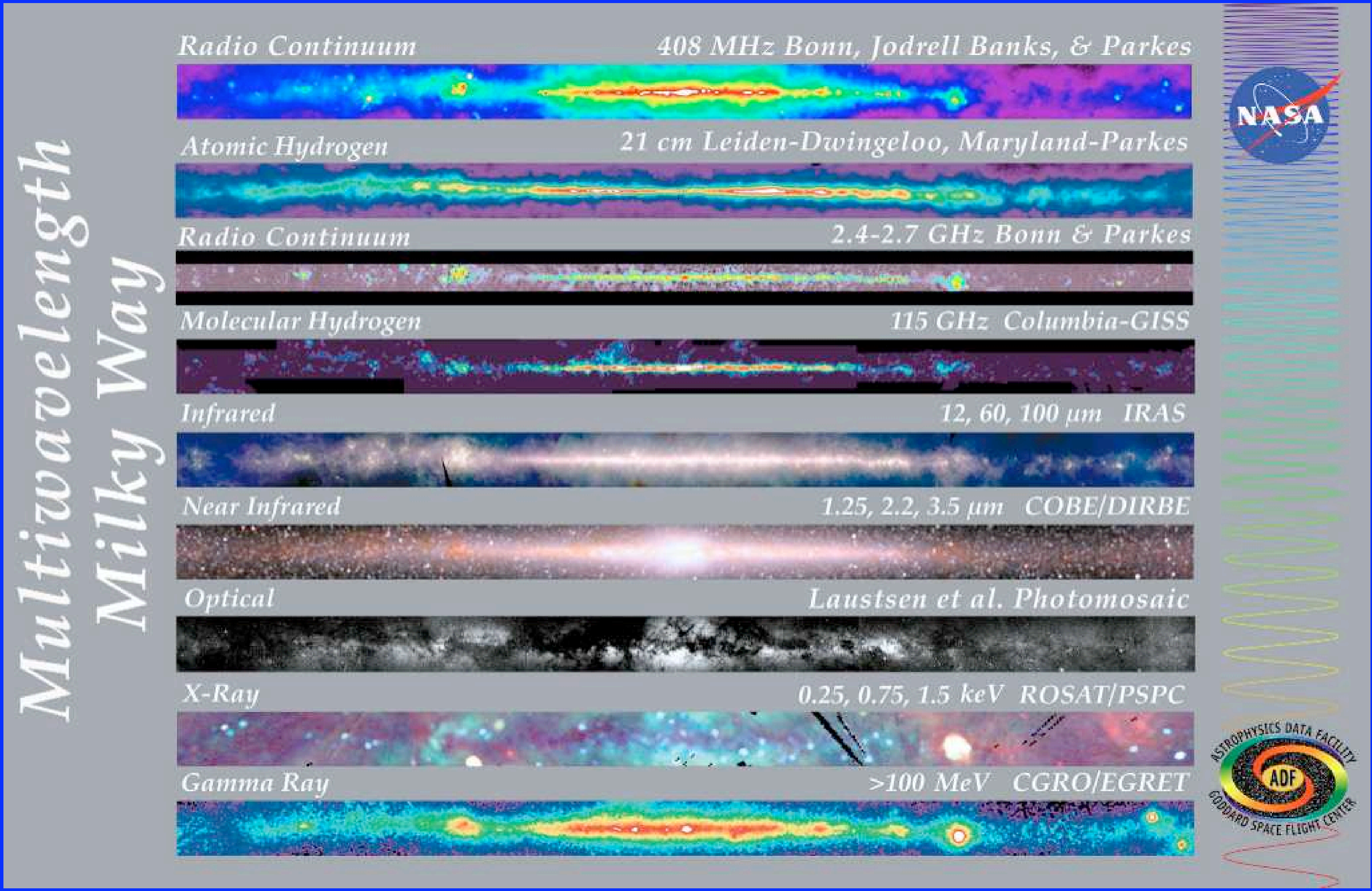
• We have a reasonable working picture of the neutrino sector, but it is not complete

• Precision cosmology is here, with much more detailed cosmological/astrophysical data on the way

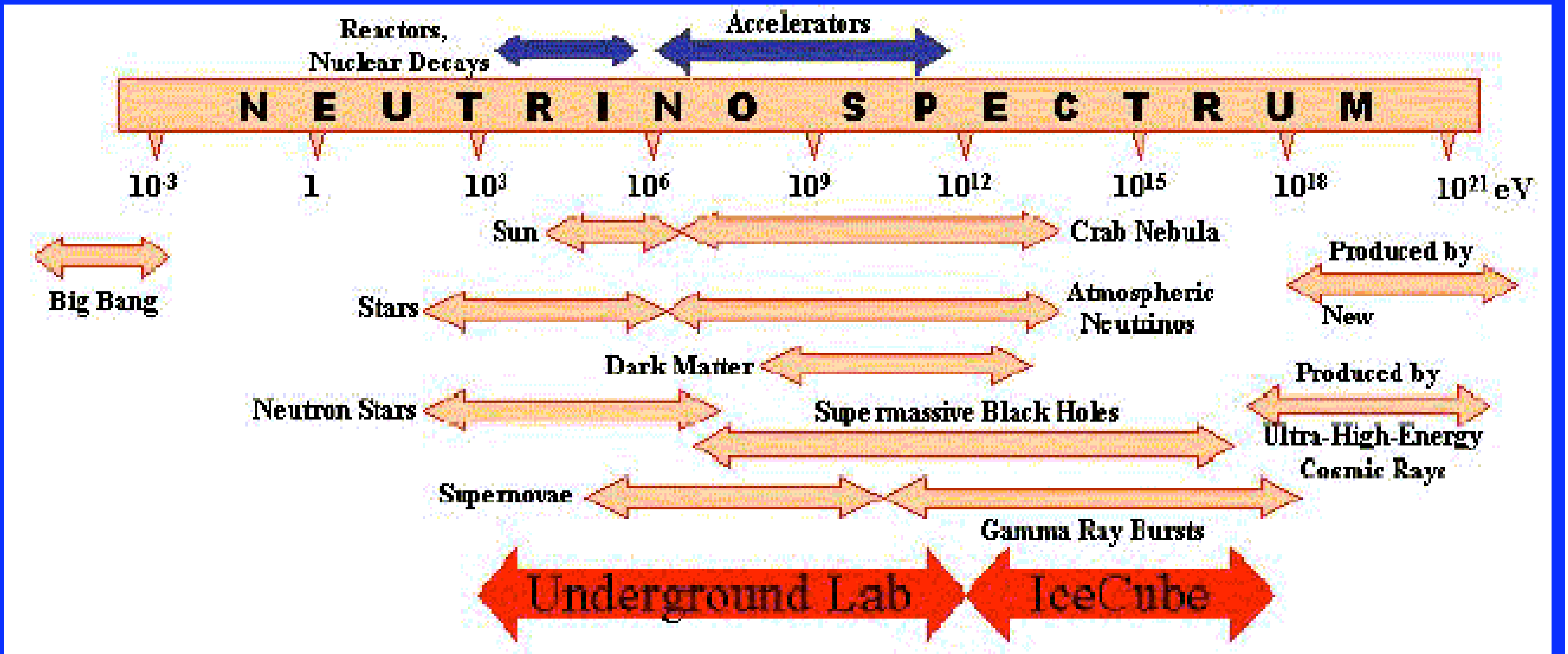
• Detection of neutrinos from various astrophysical sources is very promising

• Connections between astrophysics/cosmology and fundamental physics are now *inescapable*

Photon Windows

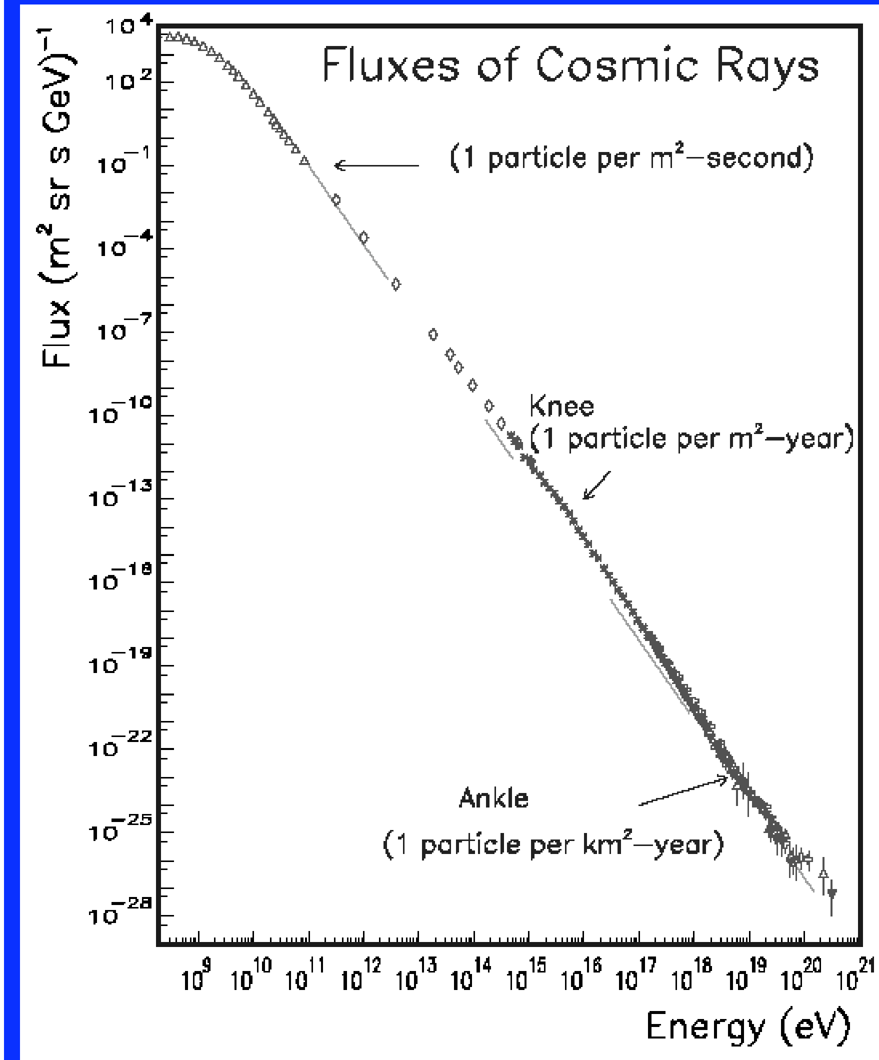


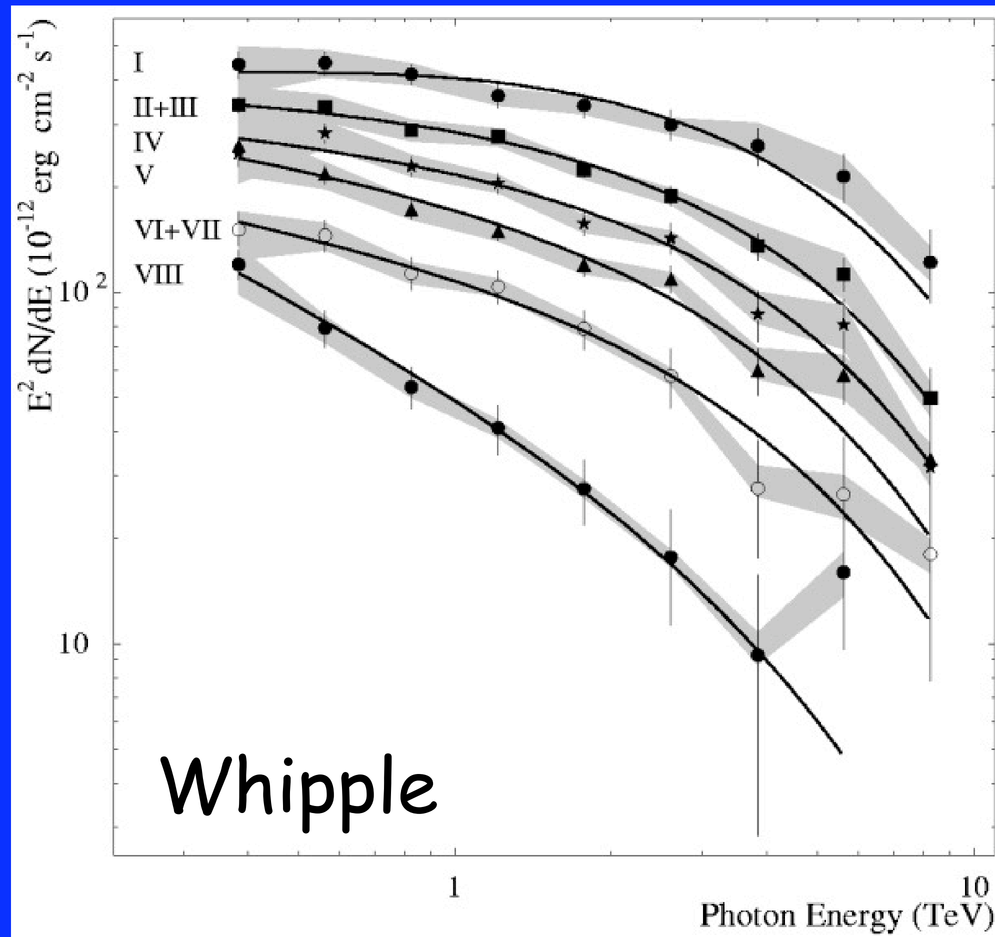
Neutrino Windows



Neutrino Facilities Assessment Committee, NAS (2002)

High Energy Messengers



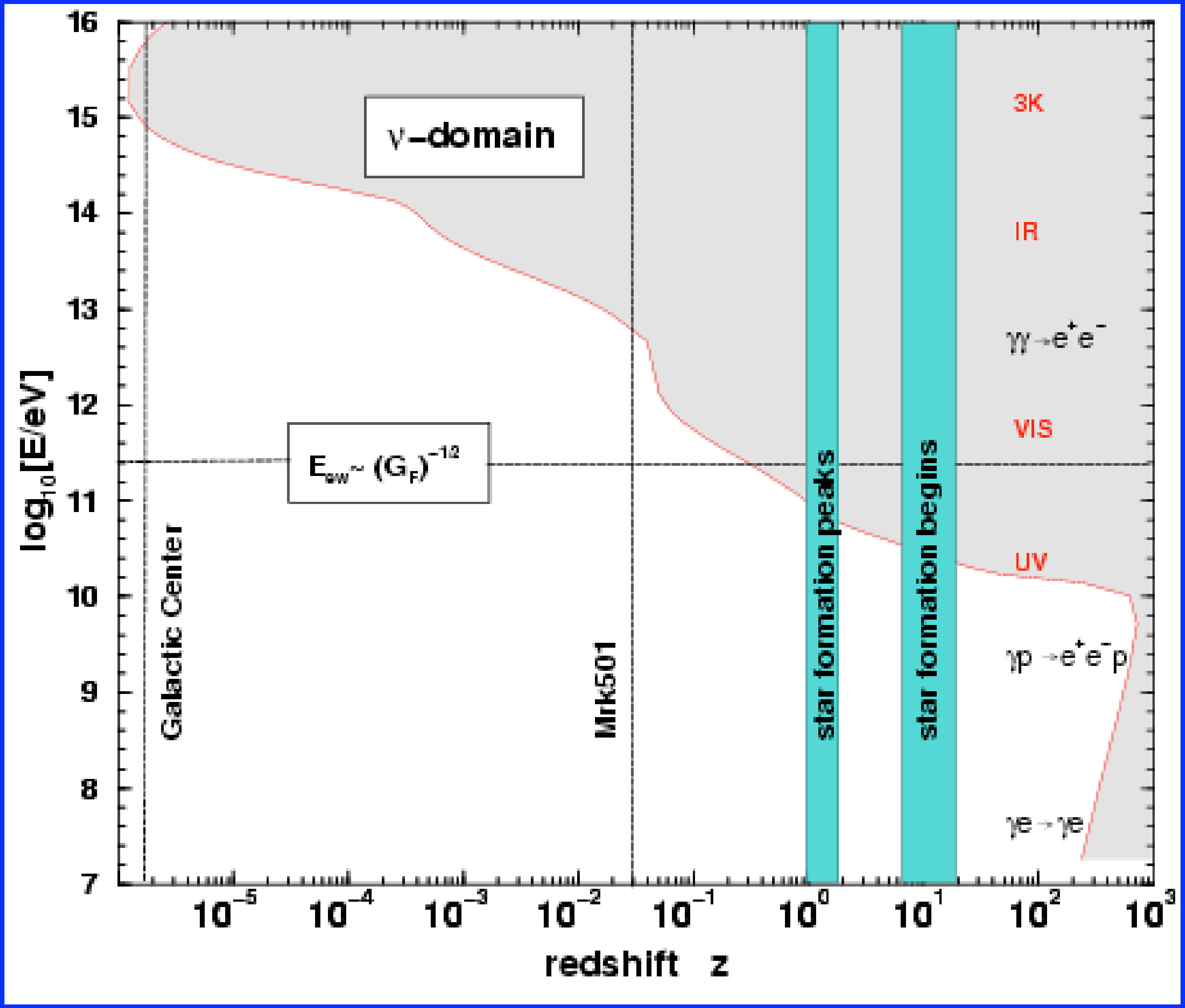


F. Krennrich et al., ApJ 575, L9 (2002)

Protons (diffuse)

Photons (Markarian 421)

Beyond the Veil

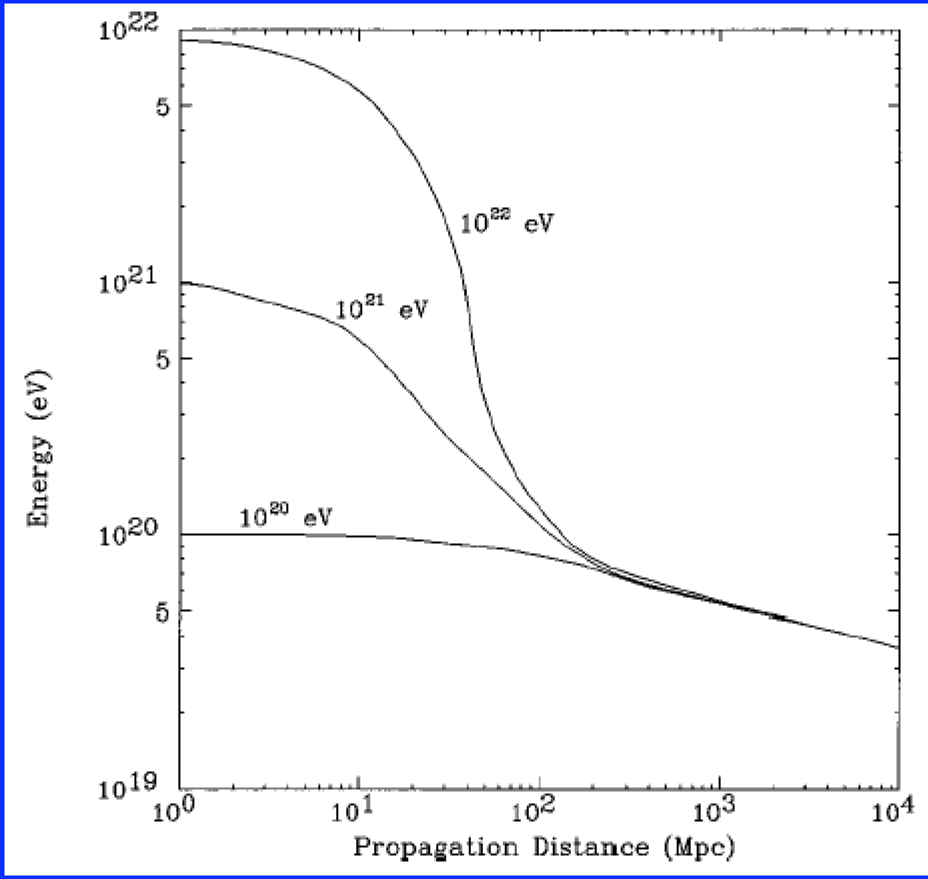


Learned and Mannheim, Ann.Rev.Nucl.Part.Sci 50, 679 (2000)

GZK Neutrinos

$$p_{CR} + \gamma_{CMB} \rightarrow \Delta \rightarrow p + \pi^0 \qquad \pi^0 \rightarrow \gamma\gamma$$

$$\rightarrow n + \pi^+ \qquad \pi^+ \rightarrow \mu^+ \nu_\mu$$

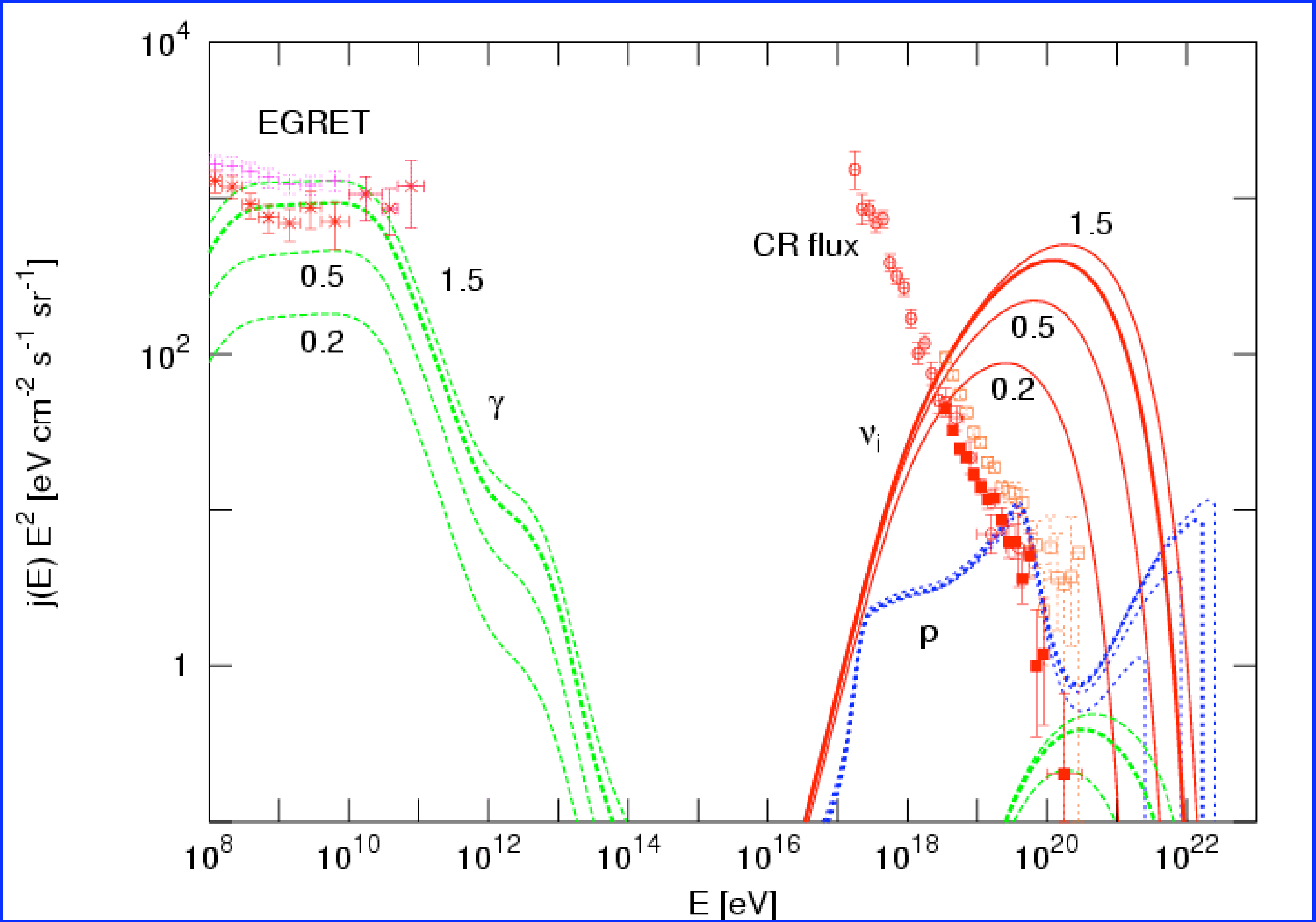


Connected observables:

- Protons
- Photons
- Neutrinos

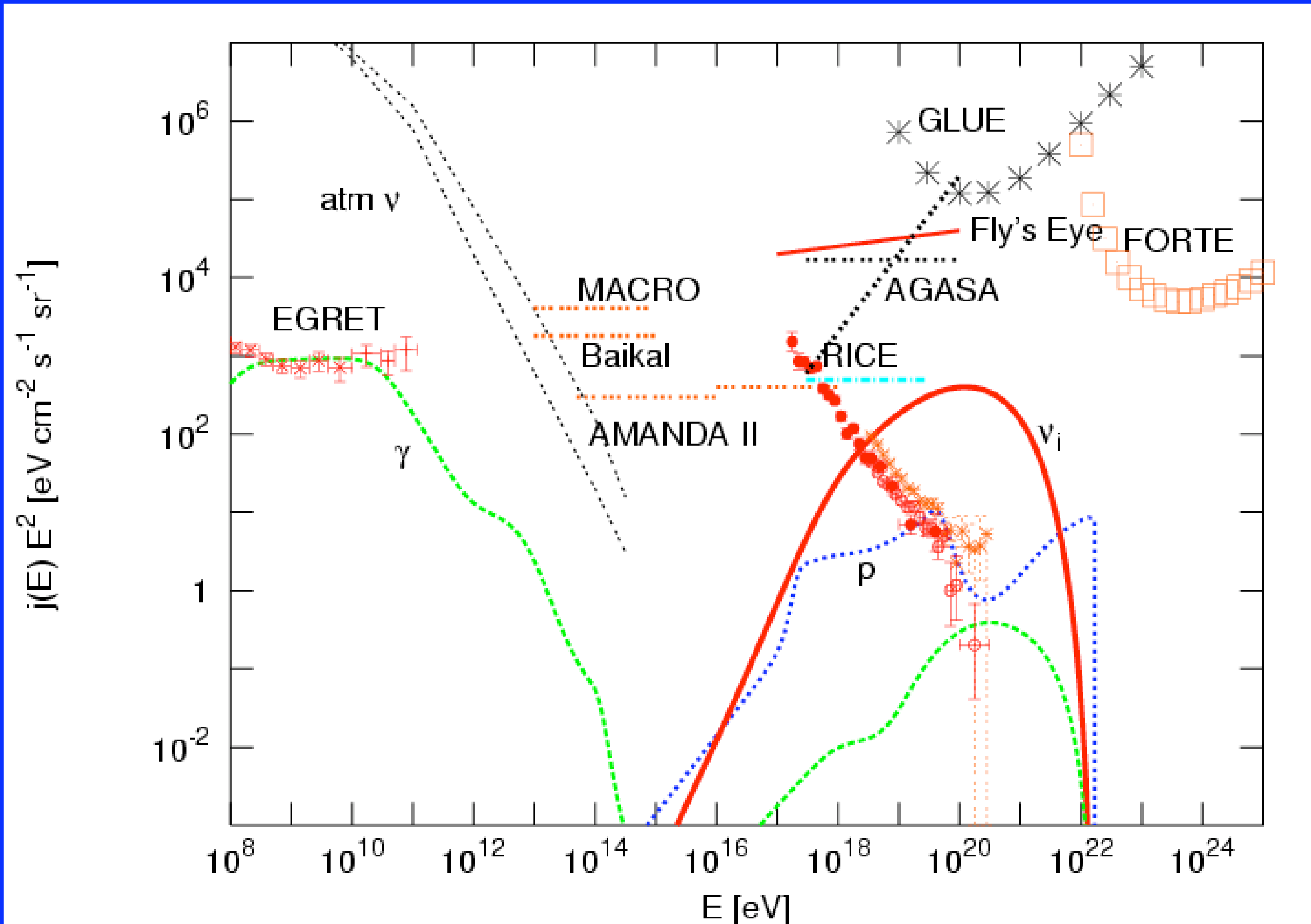
Cronin

Protons, Photons, and Neutrinos



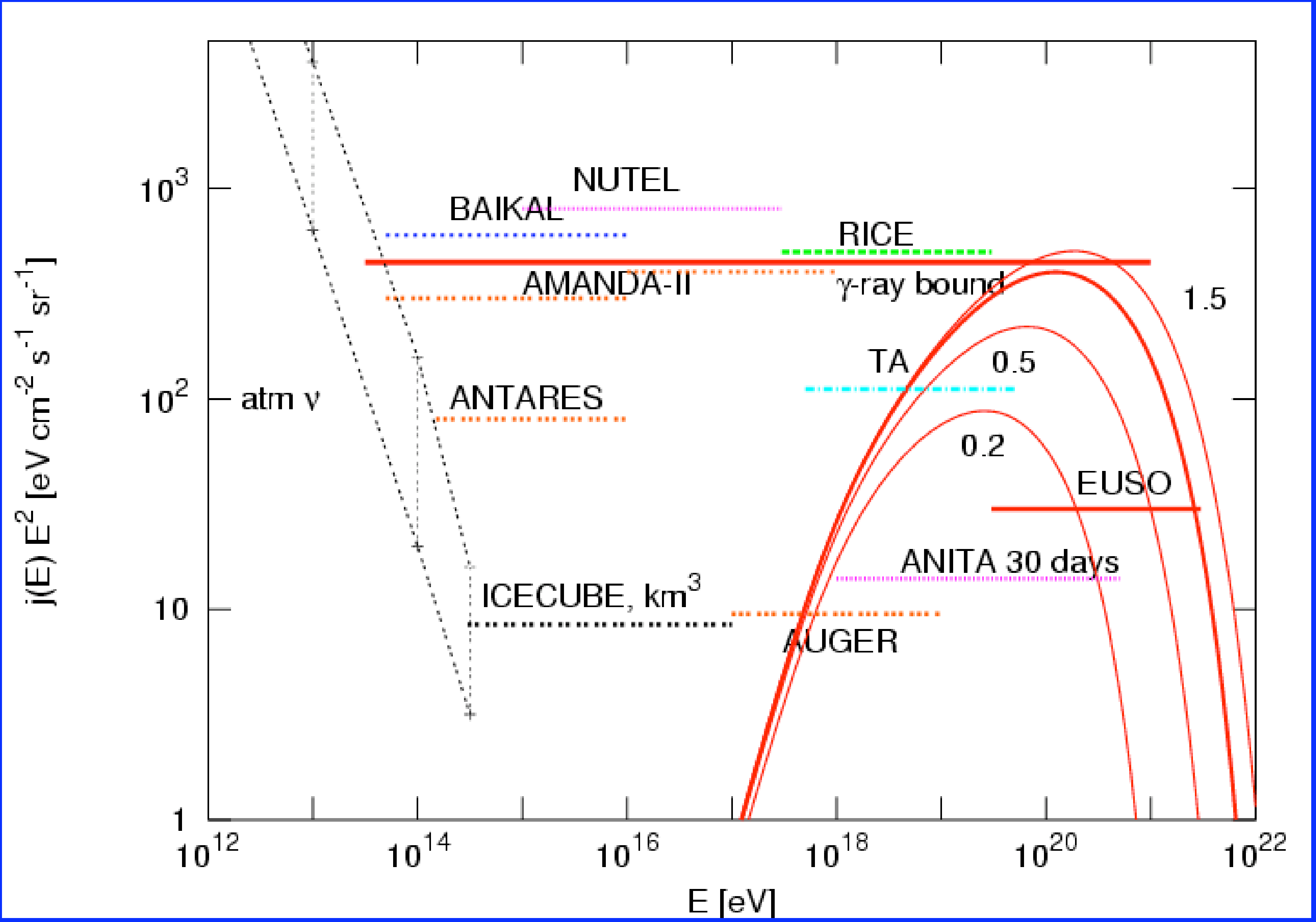
Semikoz, Sigl, hep-ph/0309328

Existing Neutrino Limits



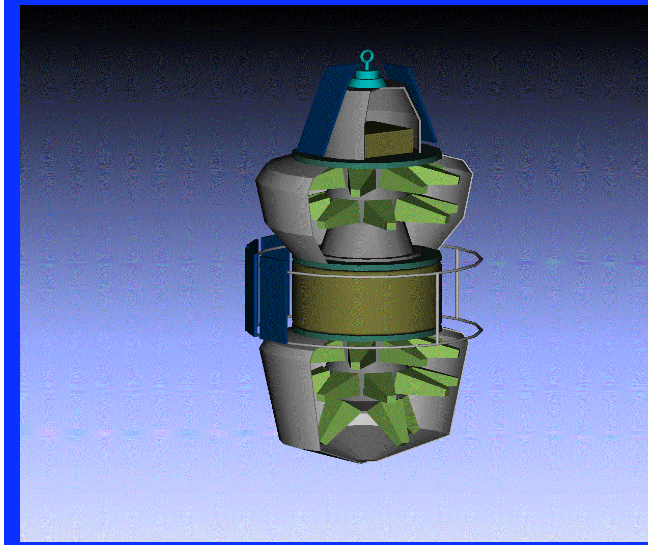
Semikoz, Sigl, hep-ph/0309328

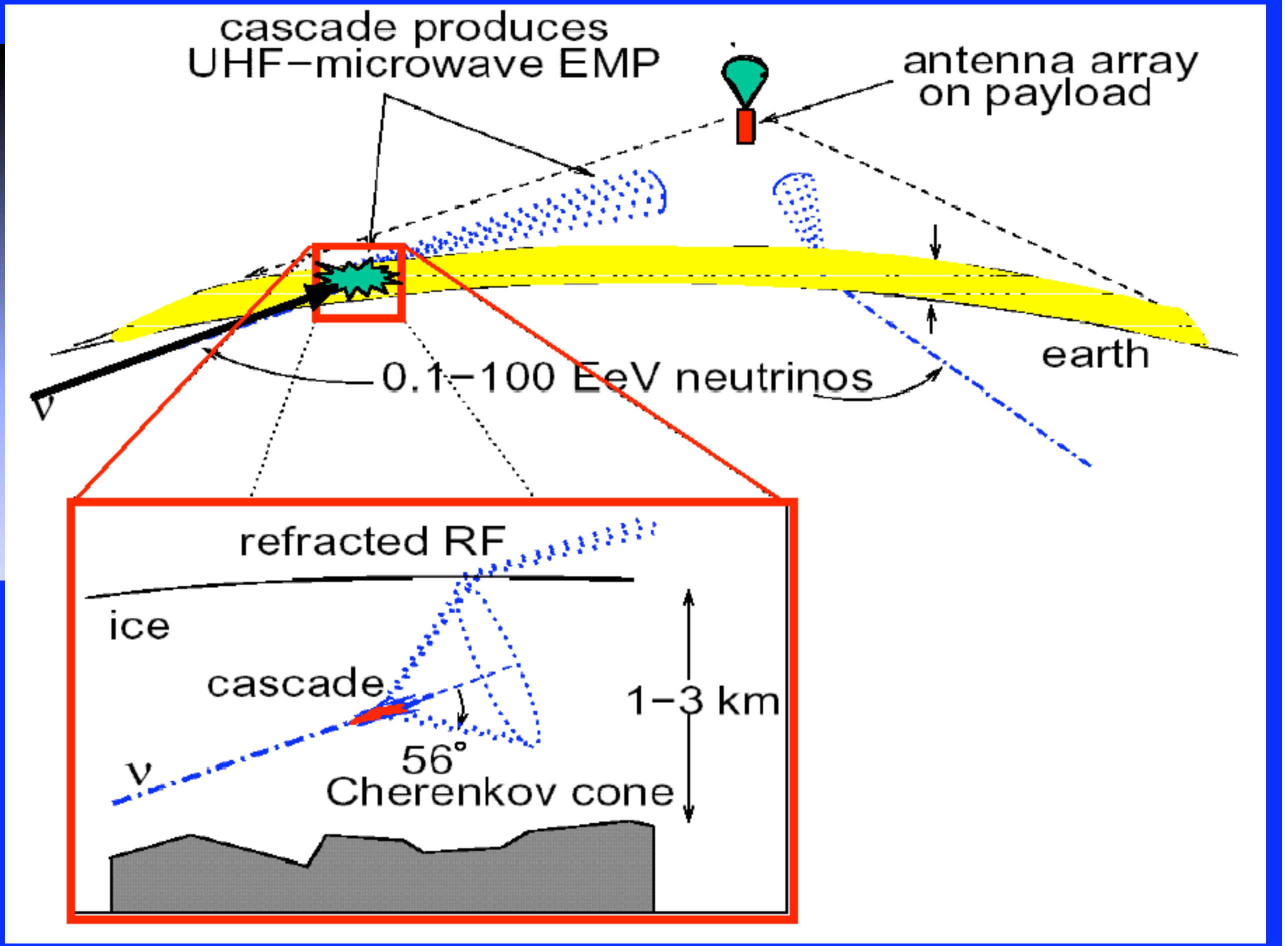
Future Neutrino Sensitivity



Semikoz, Sigl, hep-ph/0309328

ANITA



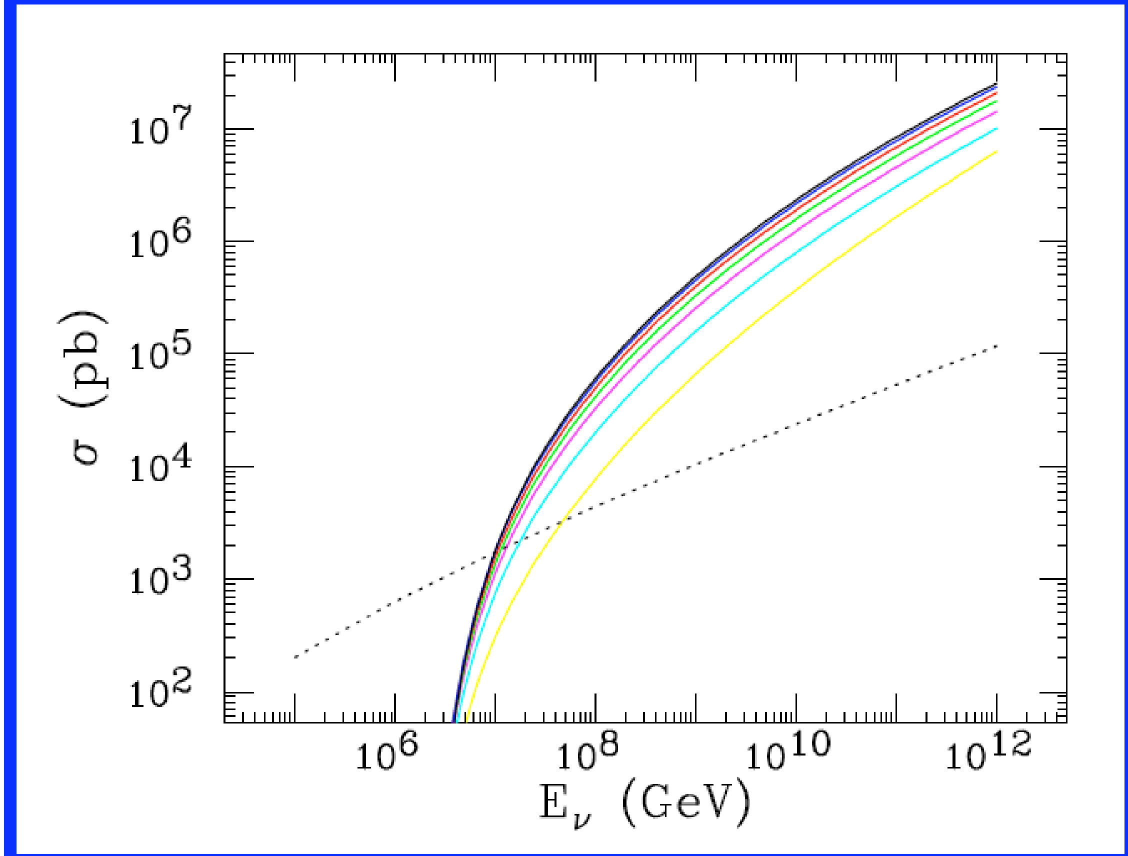


Funded 2003

Flies 2006

Predictions: Bertou et al., Astropart. 17, 183 (2002); Kusenko, Weiler, PRL 88, 161101 (2002); Feng, Fisher, Wilczek, Yu, PRL 88, 161102 (2002)

Growth of σ(ν + N)



Lower bound on flux gives upper bound on cross section, already probing E > 1 TeV

Anchordoqui, Feng, Goldberg, Shapere, PRD 68, 104025 (2003)

Domokos, Kovesi-Domokos, Burgett, Wrinkle, JHEP 0107, 017 (2001);
Tyler, Olinto, Sigl, PRD 63, 055001 (2001);
Dutta, Reno, Sarcevic, PRD 66, 033002 (2002);
Jain, Kar, McKay, Panda, Ralston, PRD 66, 065018 (2002);
Friess, Han, Hooper, PLB 547, 31 (2002)

Low-Energy Cross Sections

1. Comprehensive approach to neutrino cross sections needed
2. Neutrino-nucleus cross sections barely measured
3. Impact on supernovae
4. Impact at higher energies
5. Possibility of a muon DAR experiment

Status of our WG Report

12 sections are completed

Recommendations refined yesterday

Introduction nearly done

Full report will be available in a few days

http://home.fnal.gov/~beacom/NuStudy/
http://home.fnal.gov/~beacom/NuStudy/progress/

Connection to Neutrino Study questions

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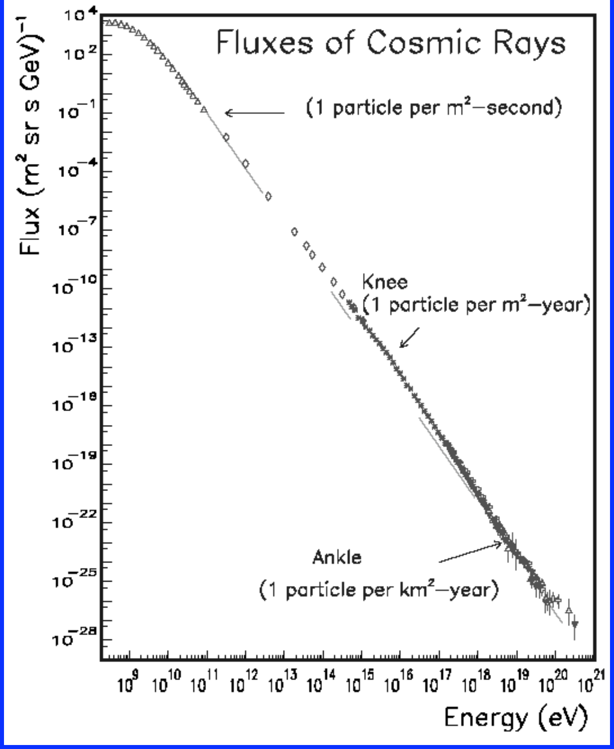


•***Opportunity:***

p, γ, ν fluxes connected

•***Potential Importance:***

Probe highest energy sources

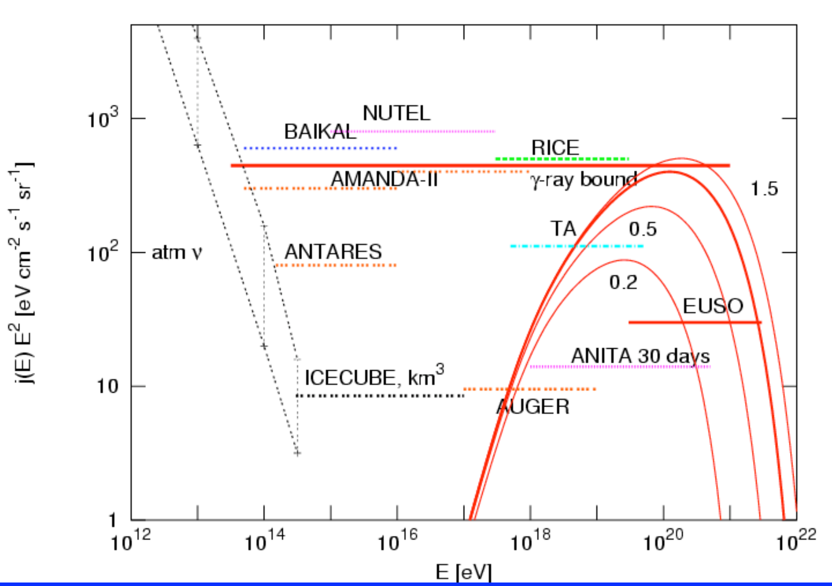
•***Primary Experiments:***

Cosmic ray arrays, GZK neutrino detectors

•***Lead Writer:***

Todor Stanev (Bartol)

2. New Physics Above the TeV Scale



- ***Opportunity:***

GZK flux bounded from below

- ***Potential Importance:***

$\sigma(\nu + N)$ at energy frontier

- ***Primary Experiments:***

GZK neutrino detectors

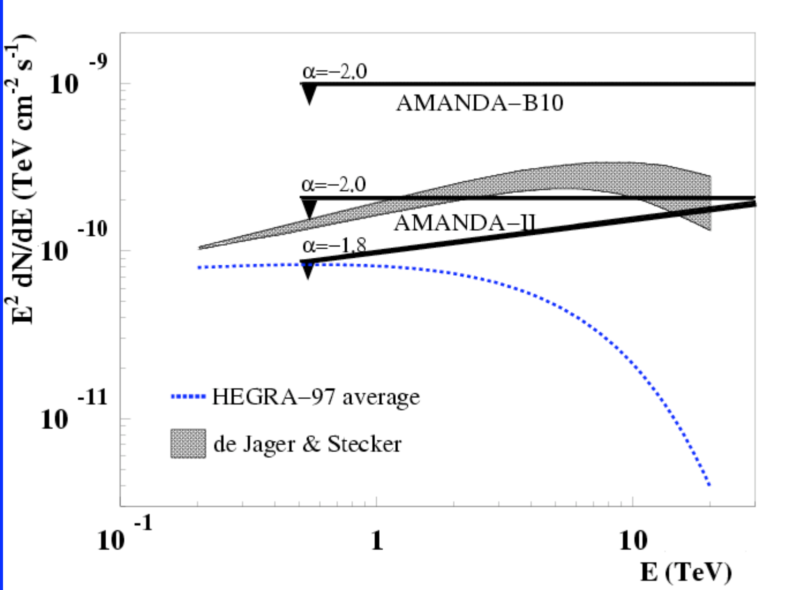
- ***Lead Writer:***

Doug McKay (Kansas)

3. Probes of HE Astrophysical Sources

•***Opportunity:***

p, γ, ν fluxes connected



•***Potential Importance:***

New understanding of sources

•***Primary Experiments:***

IceCube-like, gamma-ray telescopes

•***Lead Writer:***

Peter Meszaros (Penn State)

4. Dark Matter Searches

•***Opportunity:***

Combined accelerator, direct, and indirect bounds

•***Potential Importance:***

Nature of the particle dark matter

•***Primary Experiments:***

IceCube-like

•***Lead Writer:***

Jonathan Feng (UC Irvine)

5. Probes of Supernova Astrophysics

•***Opportunity:***

Neutrino data would help complete the SN puzzle

•***Potential Importance:***

Explosion mechanism, nuclear equation of state

•***Primary Experiments:***

Supernova detection, numerical modeling

•***Lead Writer:***

Tony Mezzacappa (Oak Ridge)

6. Supernova Tests of Particle Physics

• ***Opportunity:***
SN 1987A data was crucial to testing new physics

• ***Potential Importance:***
Much stronger limits are possible in principle

• ***Primary Experiments:***
Supernova detection, nucleosynthesis studies

• ***Lead Writer:***
George Fuller (UC San Diego)

7. Diffuse Supernova Neutrino Background

Opportunity:

SK with Gd could detect soon

Potential Importance:

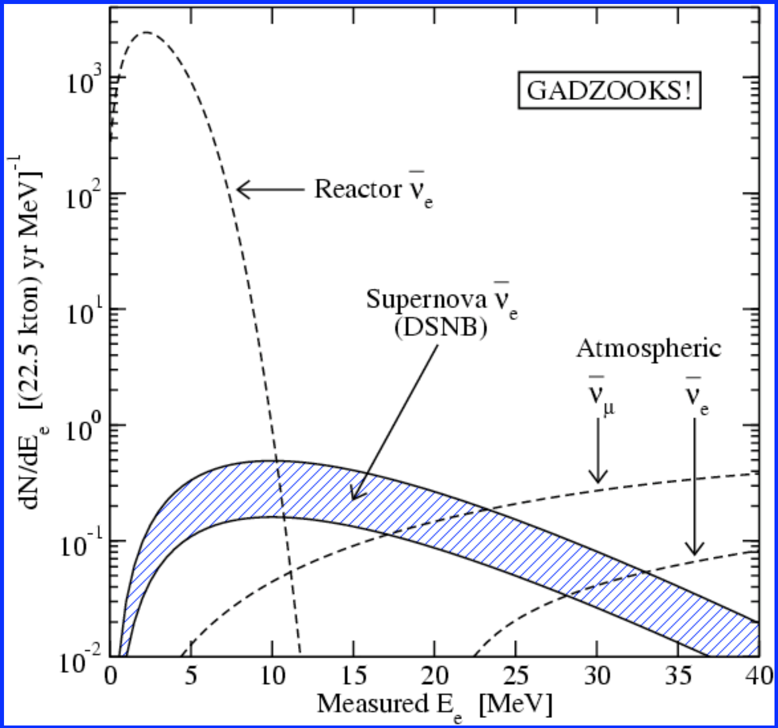
Tests supernova models, rate

Primary Experiments:

SK with Gd, UNO/HK

Lead Writer:

Terry Walker (Ohio State)



8. Neutrino-Nucleus Cross Sections

• ***Opportunity:***

Key to explosion, nucleosynthesis, and detection

• ***Potential Importance:***

Much improved understanding of supernovae

• ***Primary Experiments:***

Muon DAR neutrino sources, maybe beta beams

• ***Lead Writer:***

Vince Cianciolo (Oak Ridge)

9. Leptogenesis and the Baryon Asymmetry

•***Opportunity:***

Connects laboratory data to GUT scale physics

•***Potential Importance:***

Neutrino mass connected to baryon asymmetry

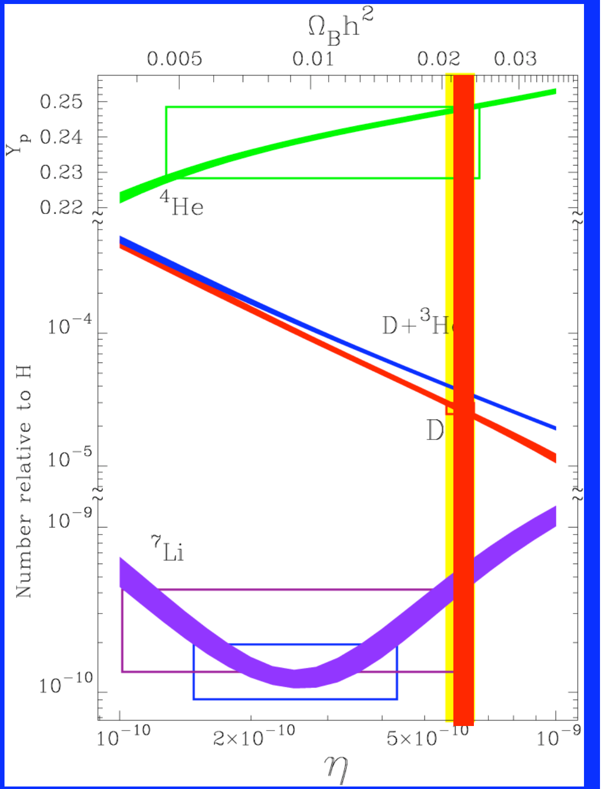
•***Primary Experiments:***

Other GUT scale probes, pencil and paper

•***Lead Writer:***

Hitoshi Murayama (UC Berkeley)

10. Precision Big Bang Nucleosynthesis



• ***Opportunity:***

Qualitatively new data

• ***Potential Importance:***

N_ν, baryon density

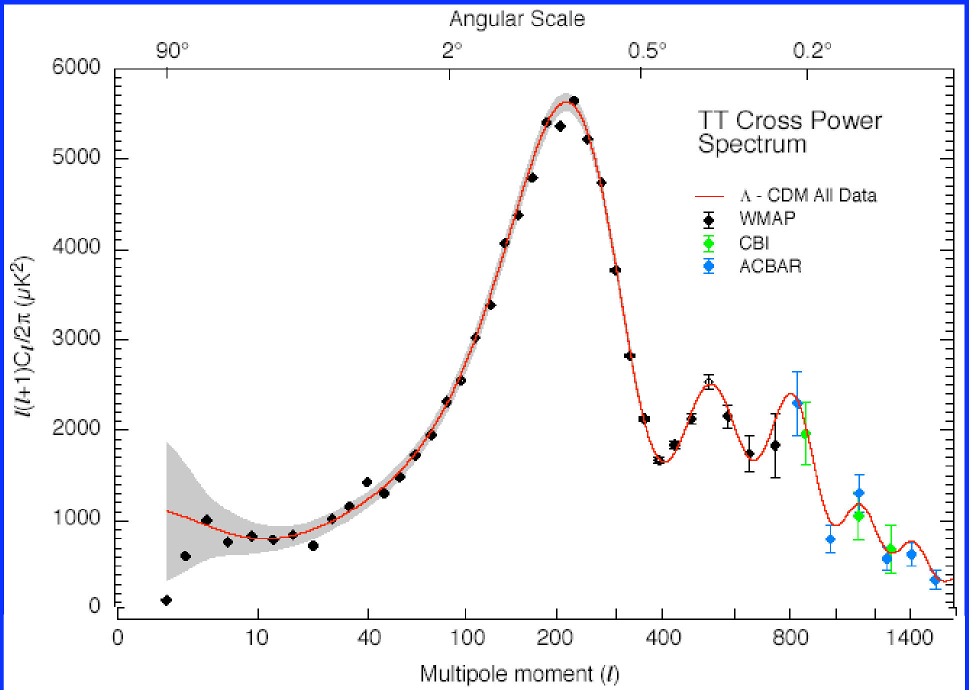
• ***Primary Experiments:***

Quasar absorption lines, low-Z stars, CMB

• ***Lead Writer:***

Keith Olive (Minnesota)

11. Precision Cosmic Microwave Background



•*Opportunity:*

Qualitatively new data

•*Potential Importance:*

very precise N_ν and m_ν

•*Primary Experiments:*

CMB satellites (polarization, high l)

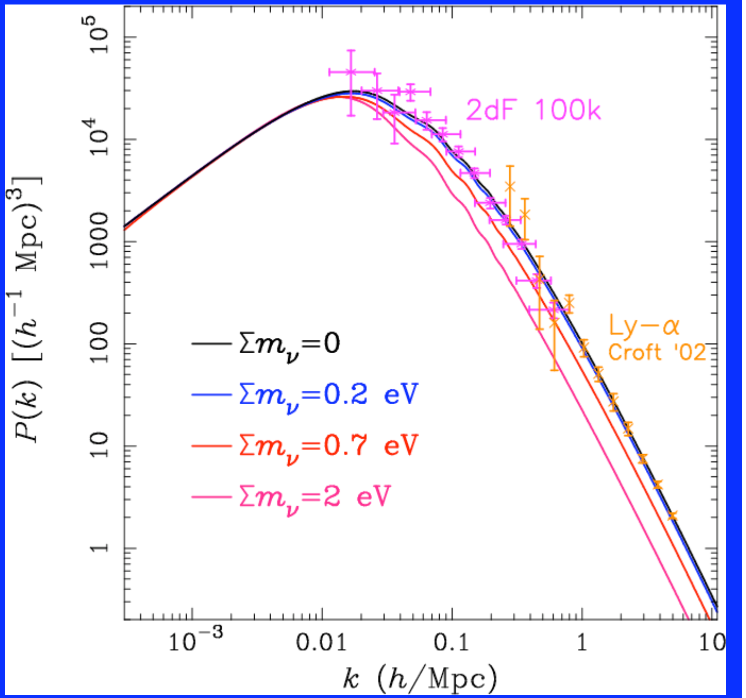
•*Lead Writer:*

Manoj Kaplinghat (UC Davis)

12. Precision Large Scale Structure

•***Opportunity:***
Precision cosmology is here

•***Potential Importance:***
First and ultimate m_ν sensitivity



•***Primary Experiments:***
Galaxy, lensing, Lyman α surveys

•***Lead Writer:***
Scott Dodelson (Fermilab)

Aftertaste of Primordial Soup

- Cosmic *neutrino* background
  Note: harder to detect than CMB

- BBN, CMB can measure N_ν
  Depends on what the meaning of "nu" is

- Possible exception with large-scale structure
  Requires neutrino masses, precision cosmology

Neutrino mass, new physics, dark matter, etc

Neutrinoless Universe

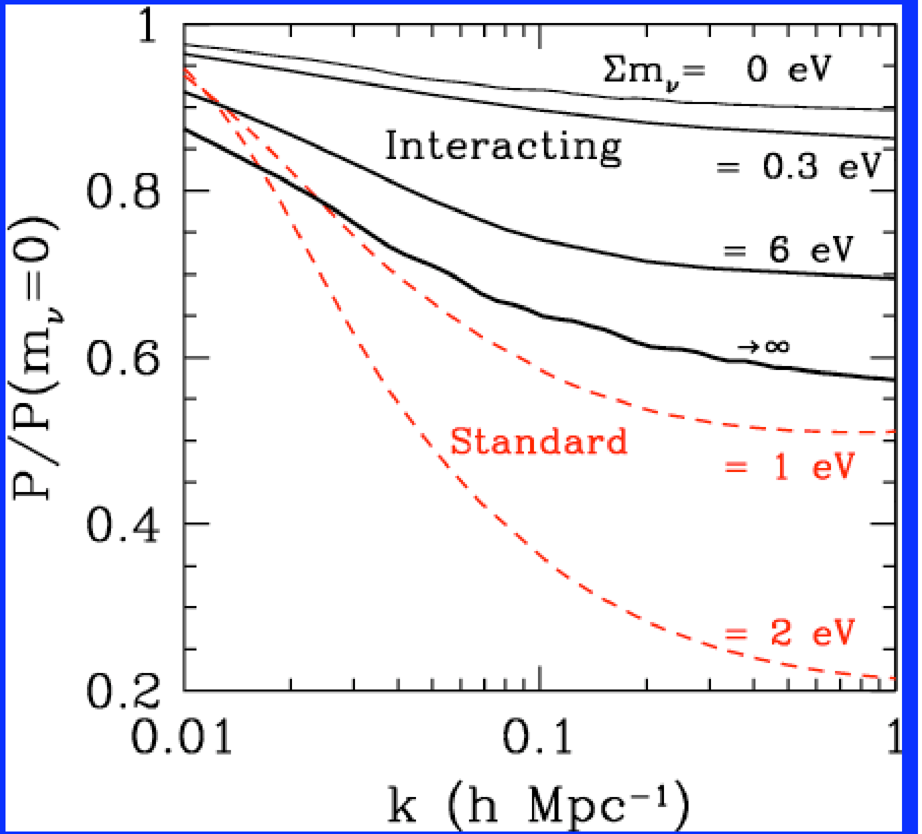
Possibility:
Neutrino mass a few eV
But no relic neutrinos

$\nu\bar{\nu} \to \phi\phi$ when $T \simeq m_\nu$

$m_\phi \ll m_\nu$

Testable both directly
and indirectly

beta, double-beta mass tests



Beacom, Bell, Dodelson,
astro-ph/0404585

Astro/Cosmo Working Group

1. New experiments in neutrino astrophysics

2. Added value to cosmological observations

3. Key role of theory in making connections

4. Strong connections to other working groups and nuclear/particle laboratory data

Contact information:

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John Beacom   beacom@fnal.gov

http://home.fnal.gov/~beacom/NuStudy/